A COMPARISON OF GROWTH RATE BETWEEN SHALLOW WATER AND DEEP WATER POPULATIONS OF SCALLOPS, *PLACOPECTEN MAGELLANICUS* (GMELIN, 1791), IN THE GULF OF MAINE

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ABSTRACT

The rate of growth over several years has been compared between two shallow water (13-20 m) and two deep water (170 m) populations of the sea scallop *Placopecten magellanicus* (Gmelin). Scallops from one shallow water population were tagged and released in 1977 for fishermen to recapture. Additional scallops from a nearby population were tagged in 1978 for periodic retrieval and measurement by divers over a subsequent four year period. The deep water scallops were sampled periodically over eight years (1976-1983), and their growth was measured through analysis of height-frequency of an anomalously numerous year class spawned in 1975. The rate of growth of the offshore, deep water scallops was found to be less than that of the inshore, shallow water scallops. The calculated maximum sizes attained, as determined by Ford-Walford plots are 150 mm for the shallow water populations and 110 mm for the deep water populations.

The giant scallop, *Placopecten magellanicus* (Gmelin), is of considerable economic importance in eastern Canada and the northeastern United States and has thus been the subject of a number of growth studies (Stevenson, 1936; Chaisson, 1949; Welch, 1950; Stevenson and Dickie, 1954; Haynes, 1966; Merrill *et al.,* 1966; Naidu, 1969, 1975; Jamieson, 1979; Posgay, 1979; Posgay and Merrill, 1979; Ehinger, 1982; Serchuk *et al.,* 1982; Serchuk and Rak, 1983; Choinard, 1984; Krantz *et al.*, 1984; Mohn *et al.*, 1984; MacDonald and Thompson, 1985; Roddick and Mohn, 1985). In all but five of these studies, age was estimated and growth was determined by the method of Merrill *et al.* (1966) i.e. counting shell rings and resilifer lines. Estimates of growth have also been made by measuring increasing weight of somatic tissue using either the adductor muscle (Haynes, 1966; Serchuk and Rak, 1983; Mohn *et al.,* 1984) or whole somatic tissue dry weight (MacDonald and Thompson, 1985). Krantz *et al.* (1984) estimated growth by measuring temperature-induced changes in $^{18}O/^{16}O$ ratios in the scallop shell calcite. Only Posgay (1963) and Naidu (1975) have measured growth through tagging and recovery thus validating age determination in the species. None of the above studies include data that show the effects of handling by repeated measurements of shell growth of scallops *in situ.*

Variations in a number of allometric relationships with depth for sea scallops have been observed (Schick *et al.,* 1987) and depth as a factor in scallop growth has been addressed previously by a number of authors (Caddy *et al.,* 1970; Posgay, 1979; MacDonald and Thompson, 1985). Posgay (1979) has noted a decrease in growth with increasing water depth for scallops on Georges Bank at four ranges between 55 and 109 m. Caddy *et al.* (1970), however, found little variation at five depth ranges between 55 and 144 m in the Bay of Fundy. MacDonald and Thompson (1985) studied growth at 10, 20, and 31 m off Newfoundland, Canada and found decreasing growth with increasing depth.

In the present study, scallops were collected from two shallow water populations (13-20 m) along the Maine coast and two deep water populations (170 m) in the Gulf of Maine to determine the extent to which the rate of growth varied with depth.

MATERIALS AND METHODS

Specimens of the sea scallop, *Placopecten magellanicus,* were collected from two shallow water and two deep-water locations in the Gulf of Maine for age and growth determinations (Fig. 1). The shallow-water animals were collected from Jericho Bay, Maine (44°11.5′N, 68°30′S), using an eight foot wide (2.4 m), three gang commercial drag in tows of 10 minutes duration. Intact animals were measured for shell height and length (Fig. 2) and then tagged by drilling a hole through the upper valve over the byssal notch area and inserting a Floy polyethylene spaghetti tag secured with knots. Other workers have demonstrated that this method of tagging is not harmful to the scallops (Posgay, 1963, 1981; Naidu and Cahill, 1985). Scallops were held out of the water for a maximum of three minutes during the tagging process and were held in running seawater tanks prior to release to minimize stress. In June 1977, 1000 scallops were broadcast over commercial fishing grounds in Jericho Bay, an area with depths ranging from 13-20 m identified by fishermen as being good scallop grounds. Tags and shells were returned by fishermen over the next three years.

Another shallow water collection of scallops was obtained in June 1978 by divers near Ringtown Island, Maine (44°07.4′N , 68°29.4′S) an island just south of Jericho Bay. These scallops were tagged, measured and placed by divers in an area protected from dragging by rough bottom conformation. They were subsequently recovered, remeasured and released in November 1978, June 1979, December 1981 and finally recaptured in June 1982 yielding the first scallop growth data showing the effects of repeated handling.

In both shallow water scallop groups, growth was determined by measuring the increase in tangential shell height of the left (top) valve between the time of tagging and time of recapture as well as measuring the height of rings formed during that time (Naidu, 1975; Posgay, 1981). Shell height at age was determined using the technique of Merrill *et al.* (1966) and a table of mean height-at-age was constructed for both groups. Since ring formation occurs during the winter and scallops spawn in the late summer, the age at first ring formation is taken as 6 months with subsequent rings found at 18 months, 30 months, etc.

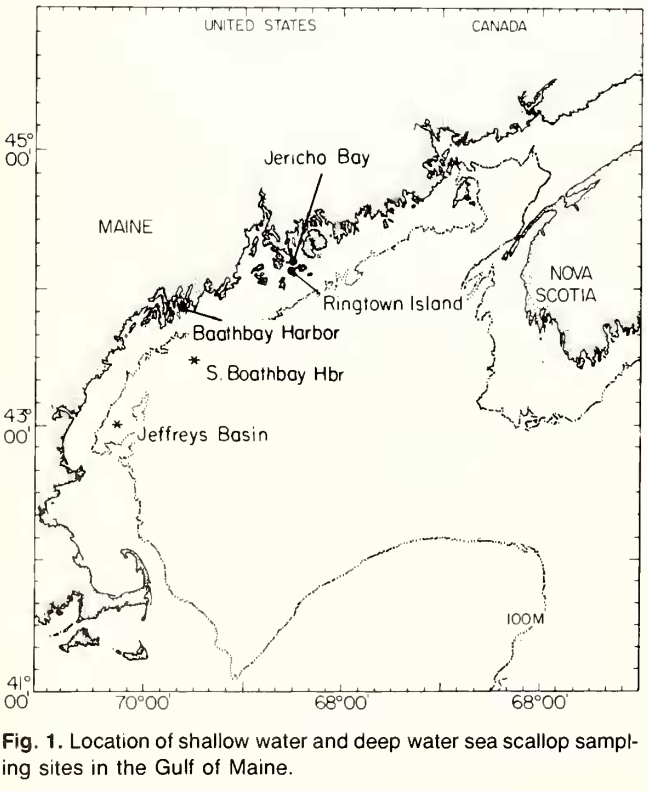

Fig. 1. Location of shallow water and deep water sea scallop sampling sites in the Gulf of Maine.

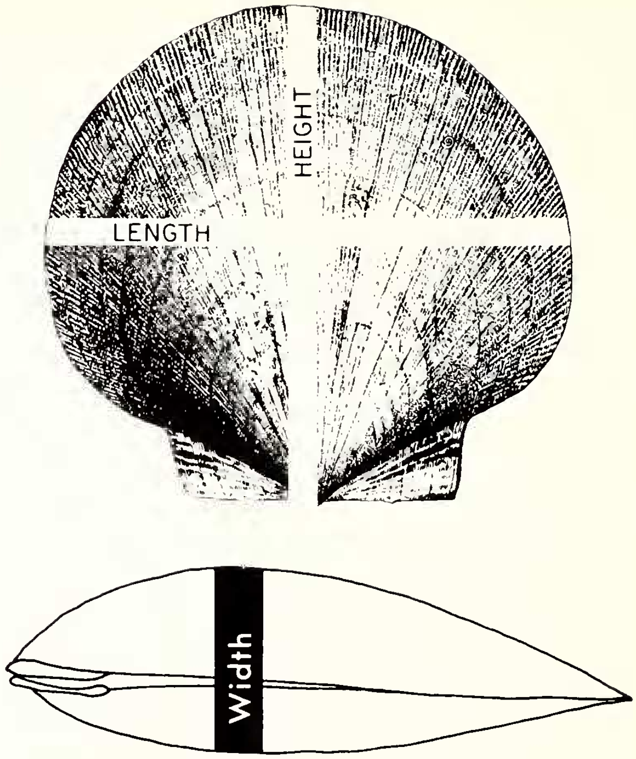

Fig. 2. Sea scallop shell conformation and dimensions.

Deep water scallops from 170 m depth in the Gulf of Maine were collected annually in August using a fine mesh, 32 ft. (9.8 m) chain footrope, semi-balloon otter trawl. Two deep water locations provided continuous records between 1976 and 1983 except in 1980 when samples were unavailable. These were: ∿32 km (20 miles) South of Boothbay Harbor (43°26.5′N, 69°33.3′S) and Jeffrey's Basin (43°04.25′N, 70° 11.33′S). Height frequency distributions over time were determined from shell heights measured to the nearest millimeter (Figs. 3, 4). The increment in shell height of a predominant year class (1975) from one year to the next was used as a measure of growth. The shell heights are for August, and since scallops spawn in August, the first height frequency is taken as scallops at one year of age, with subsequent annual collections representing scallops at 2 years, 3 years, etc. This assumption of age is based on examination of the shells from the first sample which showed one ring on each shell indicating that they had survived one winter.

Controversy still exists over the most accurate method of determining the correct age of scallops (Merrill *et al.*, 1966; Krantz *et al.*, 1984). Unfortunately, our data do little to clarify the situation. In four of the five shells of scallops retrieved alive during the second year after the Jericho Bay tag releases, there was one more ring than there should have been between the file mark and the leading edge. These shells should have contained one ring with growth before and after the ring. Instead they contained two rings with growth after the second ring. This happened in a small number of returns, but did occur in four of the five specimens, indicating perhaps more than a chance occurrence. No evidence of shell margin chipping or other damage was apparent in the shells to indicate the possibility of one of the rings being a shock mark. None of the 93 first year tag returns showed any ring formation. What caused the two rings to form in four of the five living second year tag returns is unknown. Approximately 25 scallops from the general area that were tagged and sequentially retrieved by divers over four years showed exact correlation between numbers of years and number of rings.

The offshore, deep water scallops, identified as essentially one single year class, were sampled annually and a height frequency histogram over time in the form of a 3-dimensional diagram was prepared. This histogram shows a single size mode through time. Scallops from a 1980 collection were read for shell ring structure by ten investigators. Considerable variation in numbers of rings per shell occurred between readers. The combined observed age distribution of 43 scallops from the same year class read by 10 readers was 5 at four years, 73 at five years, 237 at six years, 102 at seven years, and 13 at eight years. The problems of ring identification and the variety of aids including corroboration by resilifer marks have been addressed by Merrill *et al.* (1966) and still exist today. Also, the time from spatfall to the first readable ring, usually around 25 mm, is open to question, further clouding the relationship between a scallop's size and age.

Two problems arise in comparing the ring-structure method of age determination with the ^{18}O to ^{16}O ratio in the shell calcite method of Krantz *et al.* (1984). First, the ratio work was only performed on two shells. Second, age determination of these shells was by the method of Merrill *et al.* (1966) in which two readers agreed on age. There is enough discrepancy in age determination between the two methods to very probably negate any chance of the misreading of rings causing the difference in age. Still, the unknowns of exact age on both sides of the comparison leave the whole question open to more definitive research being needed. Our first year tag returns and our diver-retrieved aging results seem to support the one ring one year theory, yet the second year returns from the fishermen support the more than one ring per year theory of Krantz *et al.* (1984). Our offshore shells seem to indicate one ring-one year, but the reader error or perhaps the true ring number variation indicates the age determination process is still inexact.

Ford-Walford plots were constructed from shell increment measurements taken from shallow water (Ringtown) scallops to obtain an estimate of the von Bertalanffy growth equation parameters $H\infty$ and k. Ford-Walford plots were also constructed for the deep water population at 32 km south

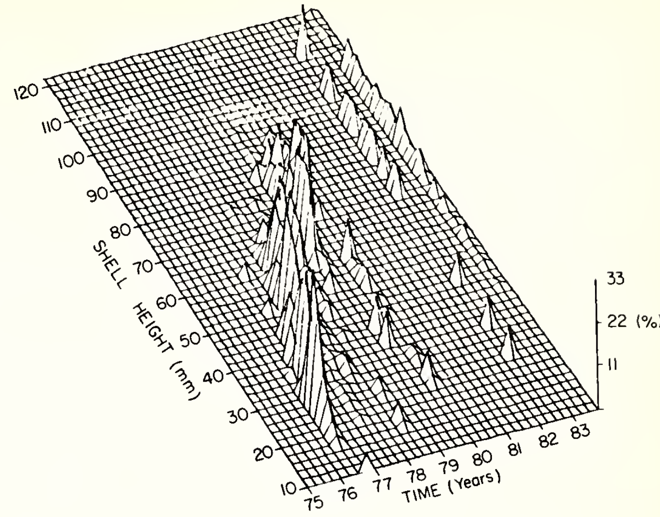

Fig. 3. Three-dimensional plot of shell height frequencies vs. time from a deep water sea scallop population located 32 km south of Boothbay Harbor, Maine.

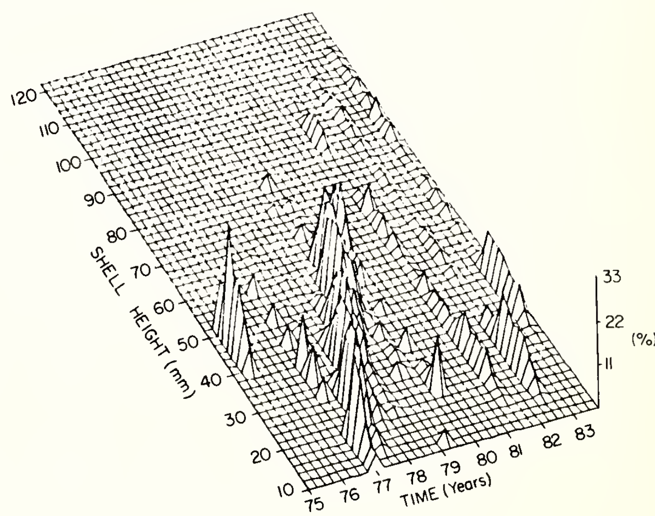

Fig. 4. Three-dimensional plot of shell height frequencies vs. time from a deep water sea scallop population located west of Jeffrey's Ledge in the Gulf of Maine.

of Boothbay Harbor using the annual growth increments in the predominant (1975) year class. The parameters $H\infty$, k, and t_0 for the von Bertalanffy growth equation, $H_t = H\infty(1 - e^{-k(t-t_0)})$, were determined from the height and age data for both the shallow-water and deep-water populations. A computer model was employed that uses an iterative process to scan a grid of options for the parameters H-infinity, k and t_0 for a least-squares fit given age-length data (Allen, 1966) and calculates asymptotic confidence intervals for each parameter (Ralston and Jennrich, 1978). All calculations were carried out on an IBM 370 computer.

Measuring growth by ring deposition in survivors of a year class can be subject to a bias known as Lee's Phenomenon (Lee, 1912) where the results depend on selection factors in mortality of that year class. Selection factors can favor slower growing scallops by killing off the faster growing individuals at a higher rate than the slower growing, smaller individuals. If this occurs, then the mean size at age of the survivors will be smaller than the mean size at age of the year class without the selecting factor and the resulting lag in mean size at age will bias the growth curve. Fishing mortality is such a factor. If the fishing gear selection is for taking larger individuals, the smaller scallops of any one year class will be more likely to survive, producing a growth curve that tails off faster than it should. In terms of von Bertalanffy parameters, the iterative process could be forced to select an H-infinity that is lower than it should be and that will force the selection of a k value that is higher than it should be. Due to the possibility of Lee's Phenomenon from a variety of factors, fishing mortality, handling of scallops, etc., it is dangerous to look at only one parameter from a von Bertalanffy curve and state that it is higher or lower than the same parameter from another curve and attach any significance to the comparison since all three of the parameters are related and interactive.

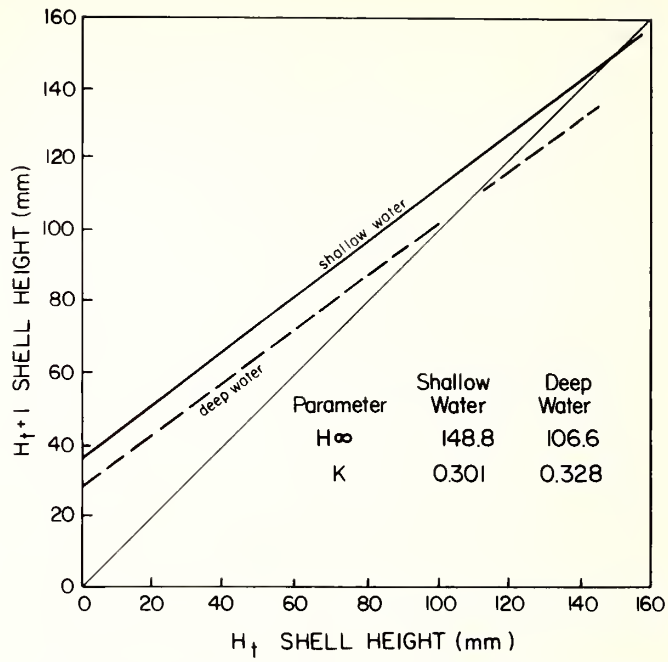

Fig. 5. Shallow water and deep water Gulf of Maine sea scallop growth: Ford-Walford plots and derived von Bertalanffy parameters.

RESULTS

Growth rates for four populations of *Placopecten magellanicus* were determined. Mean shell height at age was calculated for each shallow-water population from the shell ring measurements (Table 1) and the same was calculated for each deep-water population from the height frequency of the one predominant year class measured annually (Table 2). The same data were used to determine the von Bertalanffy growth parameters and the asymptotic confidence intervals for all four populations (Table 3).

Ford-Walford plots for the Ringtown Island population and for the 32 km south of Boothbay Harbor population indicate an H-infinity of 150 mm and 110 mm respectively (Fig. 5) which agrees closely with the empirical data (Tables 1, 2). Further evidence for the growth rate difference is illustrated in figure 6 which shows the von Bertalanffy growth curves for each of the four populations. Note that the Ringtown Island population gives a slightly lower curve than does the Jericho Bay population, but both are higher than the curves for the two deep-water populations.

In the von Bertalanffy growth equation, the parameters H-infinity and k are inversely related. At the 32 km south of Boothbay Harbor station, a heavy fishery for scallops in that area cropped off the larger scallops starting in 1981, making what appeared to be the predominant year class in the last two years' length-frequencies artificially low. An attempt to separate the year classes in the length-frequencies for 1982-1983 by NORMSEP (Hasselblad, 1966) failed, so the predominant bump was used *in toto* for both years. When the iterative process in Allen's (1966) fit of von Bertalanffy parameters to the data was attempted, it found a better fit with

Table 1. Age-at-height key for shallow water scallops. Data generated from measured rings. Heights are given in mm.

	AGE IN YEARS									
LOCATION	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
Jericho Bay	11.4	39.3	63.7	88.7	110.2	123.5	135.7	—	—	—
Ringtown Island			71.0	90.7	101.1	110.0	122.3	128.2	136.5	140.0

Table 2. Age-at-height key for deep-water scallops. Data generated from height-frequency data. Heights are given in mm.

	AGE IN YEARS							
LOCATION	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
32 km South Boothbay Harbor	27.2	51.4	64.1	75.9	—	—	101.0	103.6
W. Jeffreys Ledge	25.9	41.2	57.5	—	90.6	96.7	103.1	—

Table 3. Least squares regressions of Von Bertalanffy parameters for scallops from 4 locations in the Gulf of Maine. Values are ± 1 Asymptotic Confidence Interval.

Location	Depth (m)	H∞	K	T_O	Years fitted
Shallow Water					
Jericho Bay	25	248 ± 47.9	0.13 ± 0.036	0.17 ± .095	1-8
Ringtown Island	15	148 ± 7.7	0.27 ± 0.059	0.10 ± 0.494	1-9
Deep Water					
S. Boothbay Harbor	170	116 ± 3.7	0.28 ± 0.025	−0.01 ± 0.103	1-8
W. Jeffrey's Ledge	174	223 ± 35.3	0.09 ± 0.019	−0.37 ± 0.110	1-7

the lower H-infinity, and this raised the k value. The von Bertalanffy parameters (Table 3) and the curve (Fig. 6) for the 20 miles south of Boothbay Harbor scallop data reflects this with a more rapid rise (higher k) in early years and with a tailing off (lower H-infinity) in later years compared to the Jeffrey's Basin data.

The Ringtown Island scallops were measured by repeatedly collecting them, bringing them to the surface, measuring them and returning them to the bottom. This amount of handling could have retarded their growth in the years during the measurements. Chapman (pers. comm.) and Naidu (pers. comm.) have both indicated that handling, even slight handling in an aquarium situation, can retard shell deposition. The von Bertalanffy curve for the Ringtown Island scallop data shows good growth in the early years, before the scallops were caught, and much slower growth in the last few years. The salient point is that even with the possibility of retarded growth due to repeated handling, the Ringtown Island scallop growth is still greater than the growth of the deep-water scallops. Note that the shallow water growth curves are based on annual increments beginning at six months of age whereas the deep water growth curves are based on annual increments beginning at one year of age. The scallops sampled ranged in age from one to nine years.

DISCUSSION

The data presented here clearly demonstrate a marked

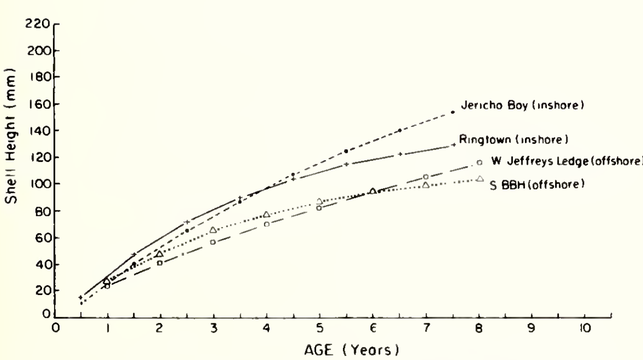

Fig. 6. Von Bertalanffy growth curves for two shallow water and two deep water sea scallop populations in the Gulf of Maine.

difference in growth rate between shallow water and deep water scallop populations and also represents the first *in situ* study of the effects of handling on growth of scallops. Our data are in general agreement with previously published growth data for *Placopecten magellanicus* and further support the theory that growth is depth dependent, with increasing depth representing deteriorating environmental suitability.

A number of authors have reported on growth rates in *Placopecten magellanicus* and their results are briefly summarized here only as they apply to the present study. Welch (1950), in one of the earliest studies of growth in this species, reported height-at-age measurements for scallops from Jericho Bay, the same area used in the present investigation. His reported average values of 46.3 mm for the second ring and 142.2 mm for the ninth ring for Jericho Bay scallops are indistinguishable from the data presented here 35 years later. Naidu (1969, 1975) monitored growth in a northern, shallow water population of *P. magellanicus* and reported H-infinity values for three locations ranging from 140 to 161 and k values for the same areas ranging from 0.19 to 0.27. These are in close agreement with those reported here for shallow water (Table 3). Posgay and Merrill (1979) reported height-at-age data for scallop samples collected by the National Marine Fisheries Service from Georges Bank and the mid-Atlantic region during the period 1958-1965. Their values for scallops collected along the Maine coast ranged from 40 mm at the second ring to approximately 143 mm at the ninth ring. Again, this compares favorably with our reported values of 39.3 and 140 mm for the second and ninth rings respectively. In a more recent study, Serchuk *et al.* (1982) presented data for scallops from the Gulf of Maine, Georges Bank and the mid-Atlantic bight. These authors showed that the scallops collected from a range of depths in the Gulf of Maine had a smaller mean size-at-age than those from Georges Bank or the mid-Atlantic bight during the first seven years.

MacDonald (1984) and MacDonald and Thompson (1985), in more recent studies of *Placopecten magellanicus*, summarized the existing information on growth in this species and compared growth at three depths in two areas off Newfoundland, Canada as well as off St. Andrews, New Brunswick, Canada and off New Jersey, U. S. A. with collaborative data from various depths in three other locations off Newfoundland. They showed that growth varied with depth at all but one location, that growth was variable between locations, and that growth differences could be attributed to measured differences in food and temperature.

Naidu (1975) found a latitudinal shift in the rate of growth such that the environment in the more northerly locations produced larger maximum-size scallops with a slower growth rate than their more southerly counterparts. MacDonald and Thompson (1985), however, found no such latitudinal differences in growth rate, nor did Serchuk *et al.* (1982). While MacDonald and Thompson (1985) demonstrated slower growth rates in deep water locations than in shallow water areas at their two sampling locations in Newfoundland, they found no differences in the Bay of Fundy near St. Andrews. The differences in growth rates recorded between sampling areas were attributed to variations in environmental parameters. It seems most likely that environmental variables such as temperature, depth and most importantly, food availability, account for the observed differences in scallop growth rates. Choinard (1984) reported the lowest growth rates to date for *Placopecten magellanicus* and attributed these slow rates to the extreme water temperature regime of the Northumberland Strait. Jamieson (1979) also reported low growth rates although not as low as Choinard for a different region of the Northumberland Straight, Central Strait, and also attributed his findings to the wide range of water temperatures in the area. Von Bertalanffy parameters for the sea scallop reported in the literature are summarized by location, author and date in Table 4.

Table 4. Parameters of the von Bertalanffy growth equation ($H_t = H\infty\ (1 - e^{-k(t-t_o)})$ for the sea scallop, *Placopecten magellanicus*.

$H\infty$	k	t_o	r^2	Location	Source
				Newfoundland, Canada	
				Port-au-Port Bay	Naidu, 1975
152	0.21	−0.48		Boswarlos	
161	0.19	−0.88		West Bay	
140	0.27	0.11		Fox Is. River	
				Sunnyside	MacDonald and Thompson, 1985
176.5	0.19	0.55	0.97	10 m	
165.5	0.20	0.63	0.97	20 m	
158.4	0.16	0.10	0.97	31 m	
				Dildo	MacDonald and Thompson, 1985
174.5	0.19	0.66	0.97	10 m	
168.2	0.19	0.37	0.96	20 m	
147.8	0.22	0.74	0.97	31 m	
				Terre Nova N.P.	MacDonald and Thompson, 1985
163.1	0.24	1.26	0.90	10 m	
151.1	0.22	0.37	0.94	20 m	
146.0	0.17	−0.88	0.92	31 m	
				Colinet	MacDonald and Thompson, 1985
158.6	0.18	0.54	0.96	6 m	
160.1	0.19	0.72	0.96	16 m	
				Northumberland St., P.E.I., Canada	
				Tormantine Bed	Choinard, 1984
103.76	0.37	0.6734		July	
108.83	0.326	0.4636		November	
114.8	0.276	−0.276		Central Strait	Jamieson, 1979
				Bay of Fundy, N.B., Canada	
				St. Andrews	MacDonald and Thompson, 1985
166.9	0.21	0.51	0.96	10 m	
166.0	0.21	0.53	0.98	31 m	
170.2	0.19	0.20	0.97	76 m	
174.3	0.22	−1.238		Gulf of Maine, U.S.A.	Serchuk *et al.*, 1982
				Georges Bank, U.S.A.	
148.9	0.26	1.0		Georges Bank	Posgay, 1962
145.5	0.38	1.5		Georges Bank	Brown *et al.*, 1972
146.4	0.35	1.4		Georges Bank	Posgay, 1976
143.6	0.37	1.0		Georges Bank	Posgay, 1979
152.5	0.34	−1.454		Georges Bank	Serchuk *et al.*, 1982
161.38	0.178	1.195		Georges Bank	Roddick and Mohn, 1985
146.5	0.30	1.32		Northeast Peak	Posgay, 1959
141.8	0.28	1.0		Northern Edge	Posgay, 1959
151.8	0.30	−1.126		Mid-Atlantic Bight, U.S.A.	Serchuk *et al.*, 1982

The effects of environmental variables on growth rate in scallops have most recently been demonstrated by MacDonald and Thompson (1985). They showed, quite convincingly, that the growth rates were directly related to a combination of temperature and food availability with low temperature and low food levels producing the smallest and slowest growing scallops. Posgay (1979) showed a decrease in mean size at age with depth at Eastern Georges Bank. Over four depth ranges from 55 m to 100 m, Posgay showed a decrease in mean size at the fifth ring from 119 mm to 94 mm. Caddy *et al.* (1970) however, did not show significant differences with depth over the five depth ranges from 55 to 144 m in the Bay of Fundy. The mean size of scallops at the fifth ring in their study showed no significant differences between samples. Since these two studies represent different sample sites, it is likely that the differences in growth rates can again be attributed to environmental differences. It is interesting to note here that the Bay of Fundy scallops in both studies, Caddy *et al.* (1970) and MacDonald and Thompson (1985), were the animals that showed no differential growth with depth probably due to hydrographic homogeneity created by strong tidal mixing.

Studies are currently underway to assess the available food rations for the two populations being studied here. It would appear that the reported slow growth rates and smaller size-at-age for the deep-water scallops are primarily due to a lack of suitable food items (Shumway *et al.*, 1987).

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